PROJECT PATHFINDER

AUTONOMOUS RENDEZVOUS AND DOCKING PROJECT PLAN

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PATHFINDER

AUTONOMOUS RENDEZVOUS AND DOCKING

PROJECT PLAN

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FOREWORD

Project Pathfinder is a research and technology program which will allow the National Aeronautics and Space Administration (NASA) to strengthen the technology base in support of the civil space program and enable a broad set of new space missions. Through Pathfinder, the NASA Office of Aeronautics and Space Technology (OAST) will develop a variety of high leverage technologies that will support a range of future missions including a return to the moon to build an outpost, piloted missions to Mars, and continuing exploration of other planets.

NASA's potential missions to the moon and to Mars will require the use of orbiting spacecraft with smaller modules that will go to and from the lunar or planetary surface. The capability for autonomous rendezvous and docking with the orbiting element is required for both manned and unmanned missions. The Pathfinder Autonomous Rendezvous and Docking Project will develop and validate the technologies for this new capability. The project will focus on the development of sensors and mechanisms, trajectory control requirements and techniques for operations in lunar and planetary orbits, and associated guidance, navigation, and control algorithms. Prototype hardware and software will be developed and demonstrated in test beds, flat-floor facilities, and in flight.

For additional information on the Autonomous Rendezvous and Docking Project or this document, please call the OAST Information Sciences and Human Factors Division (RC), at ext. 2743.

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SECTION 1

INTRODUCTION

1.1 Objectives of this Document

This document is the Autonomous Rendezvous and Docking Project Plan. This document will provide top-level, authoritative guidance and information on the scope, content, and long-range plans of the Autonomous Rendezvous and Docking Project. The objectives of this document are complementary to the Pathfinder Program Plan and provide the detailed project plan for this element of the Pathfinder Program. The document defines the work breakdown structure, the technical goals and objectives of this program element and its constituent work packages, the management approach, including structure, participating centers and individual roles and responsibilities, and accountability, resource allocations, and associated schedules, milestones, and deliverables, and long-range Autonomous Rendezvous and Docking Project planning.

1.2 Pathfinder Program Overview

The Pathfinder Program is a National Aeronautics and Space Administration (NASA) initiative to develop critical capabilities for the future of the civil space program. Pathfinder does not, in itself, represent a commitment to any particular mission. However, through Pathfinder, the NASA Office of Aeronautics and Space Technology (OAST) will develop a variety of high-leverage technologies that can be applied in a wide range of potential future NASA missions. Project Pathfinder is organized into four programmatic thrusts:

(1) Exploration
(2) Operations
(3) Humans-in-Space
(4) Transfer Vehicles.

The Autonomous Rendezvous and Docking Project (AR&D) is one of five projects under the Operations thrust. More information on Pathfinder can be found in the Pathfinder Program Plan.

1.3 Mission Studies and Technology Requirements

The Pathfinder Program focuses on the capabilities required for both manned and unmanned missions to the Moon and Mars. Most of the mission scenarios require the use of orbiting spacecraft with smaller modules that will go to and from the lunar or planetary surface. Rendezvous and docking operations are required. Autonomous rendezvous and docking are enabling technologies for unmanned missions, where the signal delays preclude teleoperations.

still be required because of the limitations of ground tracking in a Mars orbit and the communication time delays between the Earth and Mars orbit.

The implementation of autonomous rendezvous and docking requires the development of several critical technologies: (1) sensors for long- and short-range navigation; (2) guidance, navigation, and control (GN&C) algorithms and trajectory control techniques for rendezvous and docking of manned and unmanned vehicles in lunar or planetary orbits; and (3) docking mechanisms which are unique to the Mars environment and accommodate long-periods of dormancy.

Measurements of relative position, velocity, attitude, and attitude rates are critical to rendezvous and docking operations. The onboard rendezvous sensors on the Shuttle (star tracker, rendezvous radar) are inaccurate with respect to performance expectations for planned unmanned systems, and require extensive crew monitoring. By design, they are inadequate for ranges less than 90 feet. Shuttle rendezvous systems were designed with manned operations and typical Shuttle missions in mind, hence their unsuitability to Pathfinder goals and objectives. The radars being considered for the Orbital Maneuvering Vehicle will also be ineffective at very close ranges. The Global Positioning System (GPS) can provide relative navigation in low Earth orbit, but its performance and space application must be proven. GPS will not be adequate for close-range maneuvering and docking. No suitable long-range radars are available which meet the power, weight, and performance requirements of the Mars Rover/Sample Return Mission.

The AR&D Program will develop sensors for short- and long-range navigation, with the goal of meeting the total set of navigation requirements with a minimum suite of sensors. Emphasis will be placed on maximum applicability of these sensor technologies across the span of Pathfinder missions. The AR&D Program will make maximum use of current technology developments. As an example, a prototype laser docking sensor is being developed for a flight experiment on a Shuttle flight, which could support terminal rendezvous, station keeping, approach, and docking. This sensor can provide navigation measurements from zero to three miles. Further work is needed to enhance the applicability of this sensor to the Pathfinder Program. Its effective operating range must be extended, while minimizing its power, weight, and volume. Other candidate sensors such as millimeter radar and vision sensors require further evaluation and development.

For the Pathfinder Program, it is anticipated that a near-term AR&D demonstration can be accomplished by modifying or expanding the capabilities of existing or emerging sensor technologies. However, an advanced sensor such as a vision sensor will require longer development time to attain sufficient maturity for a demonstration. Such advanced sensors will be targeted for a far-term AR&D demonstration.

1.6 Technical Approach

For candidate Pathfinder mission scenarios and corresponding vehicle configurations, coordinated systems-level rendezvous and docking requirements will be defined. Performance requirements of the AR&D hardware and software will be established.

Hardware and software technologies to meet these requirements will be identified and current technologies will be assessed for applicability. AR&D capabilities will be segregated into near- and far-term programs, based upon readiness levels of required technologies and specific Pathfinder mission plans.

Maximum synergism between near and far-term programs will be implemented, with major differences expected in the technologies of the relative navigation sensors. Trajectory control requirements and techniques for AR&D will be defined and candidate GN&C designs will be developed to implement these AR&D capabilities. Six and twelve degree-of-freedom simulations will be used for performance, dispersion and sensitivity analyses and trade studies of the integrated designs.

Results of these evaluations will be used to establish the specifications for prototype sensors. Prototype sensors and hardware/software emulations will be developed and incorporated into test bed proof-of-concept demonstrations. Results of synergistic technology and advanced development programs, such as the laser docking sensor flight experiment, will be incorporated into the program. Flat-floor facilities will be used for ground demonstrations of the final docking operations.

Figure 1.2 depicts the progression from requirements definition, to development of system level performance requirements, preliminary development, and finally to ground based tests that comprise Pathfinder AR&D development. The figure shows the interdependency of the various tasks as well as the role of program planning in coordinating the execution of these tasks.

SECTION 2

PROGRAM DESCRIPTION

2.1 Work Breakdown Structure

The Autonomous Rendezvous and Docking Project is divided into three major work packages: (1) Systems Integration; (2) Guidance and Control; and (3) Sensors and Mechanisms. These work packages are structured to provide focus on specific technology development areas.

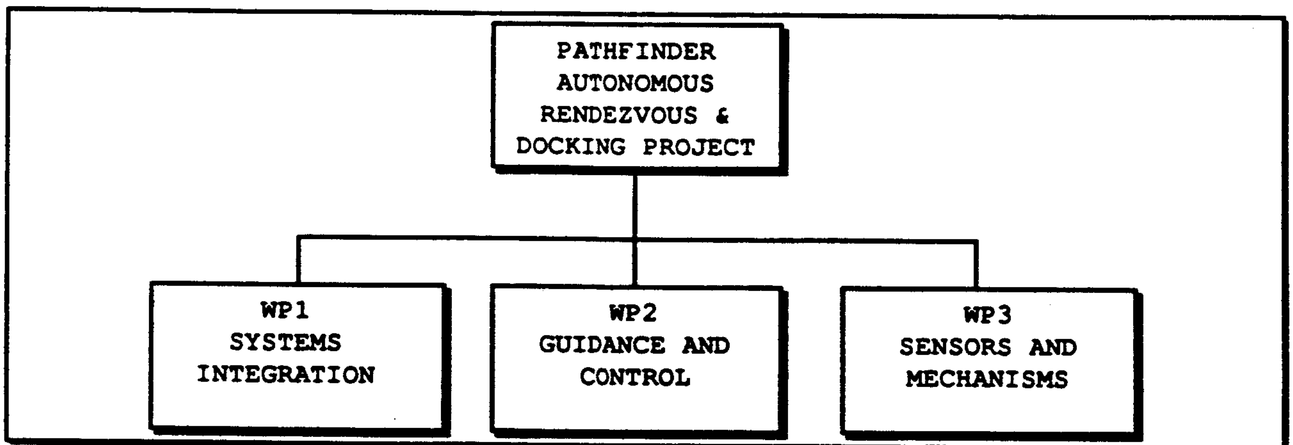


Figure 2.1 - Pathfinder AR&D Work Breakdown Structure (WBS).

2.2 Management Plan

2.2.1 Management Structure

Figure 2.2 shows a Lead Center management plan structure for the Pathfinder AR&D project. Advantages of this type of management structure for the Pathfinder AR&D Project include clear identification of accountability for project definition, implementation and deliverables, single point of interface between NASA headquarters and the Lead Center and flexibility to dynamically adjust task assignments and resource allocations in a timely manner.

The overall Pathfinder AR&D project will be managed by a Program Manager in Code RC. An intercenter working group including JSC, MSFC, JPL, AMES, LaRC will make recommendations to Code RC regarding AR&D definition and planning and will function as a steering committee to review any appeals to assignments of tasks or resources to the NASA centers.

JSC, as the Lead Center, will provide technical coordination, reporting, scheduling and progress against milestones and will recommend resource allocations and task assignments to Code RC. Par-

2.2.3 Program Planning

The AR&D Project Plan is an initial five year plan, de cooperatively by the Lead Center with the Participating Ce. This document will establish program content, task assignme resource allocation and milestones. Formal reviews of tasks by NASA centers with Code RC will provide a mechanism to modify the program plan as required and to project the focus of long range tasks.

2.2.4 Program Reporting

Pathfinder elements will be managed under existing Research and Technology Objectives and Plans (RTOP) guidelines. Pathfinder AR&D reporting strategy will use RTOP reports as the basis for assessment by Code RC. A status report is prepared in the January timeframe to support submission of NASA budgets to congress, in the June timeframe to support the RTOP call process and in the August timeframe to document progress for the current fiscal year and review requirements for the succeeding fiscal year.

Pathfinder AR&D Project will report status against the AR&D Project Plan in accordance with the following table:

Reporting Period	Reporting Objective
August	Report progress for the current fiscal year and project focus for succeeding fiscal years.
January	Support of submittal of NASA budgets to Congress.
March	Support of PASO preparations.
June	Support of RTOP call process.

Table 2.1 - Pathfinder AR&D Project Reporting plan.

To the extent possible, standard RTOP reporting requirements will be used to satisfy management visibility for the Pathfinder AR&D Project.

2.4.2 Technical Approach

The objectives of this work package are achieved by the performance of several tasks including: (1) Program Planning Support, (2) Systems and Mission Analyses, (3) Trajectory Control Analyses, and (4) Guidance, Navigation and Control (GN&C) System Integration.

The Autonomous Rendezvous and Docking (AR&D) Project Plan is maintained on a yearly basis to provide management overview and coordination, and integration with the Pathfinder Program plan to ensure continuing compliance. Technical interchanges and workshops are conducted to provide intercenter, industry and academia participation in data interchange on the associated technology developments and assessments of options. Technical and programmatic reporting are provided to ensure management insight into the status of the AR&D Program.

Under this task, systems-level studies are performed to provide direction and focus to the detailed technology development studies. These systems-level studies include the definition of AR&D systems requirements, coordinated with Pathfinder Program mission requirements. The corresponding technology requirements will be defined and correlated to specific Pathfinder mission scenarios. The various options to meet the technology requirements will be assessed to select the most applicable and achievable candidates. The capabilities for near-term and far-term demonstrations will be defined, based on the mission requirements and projections of technology development schedules.

AR&D technology components will be integrated in high-fidelity guidance, navigation, and control (GN&C) simulations to ensure that the individual technologies meld into a viable and effective system design. These simulations will also be used to compare various technology options.

When the AR&D technologies mature to prototype development, this work package will establish the requirements for proof of concept demonstrations. For ground demonstrations, the test plans and facility usage plans will be developed and coordinated. For flight demonstrations, sponsoring organizations will be sought and support for the manifesting process provided.

In the early phase of the AR&D Project, a number of options will be pursued in parallel for concept development and evaluation of a broad spectrum of applicable technologies. Under this task, these options will be evaluated and compared against specific Pathfinder Program mission requirements. Trade studies results will be evaluated to select among competing options for further development.

As the AR&D technologies mature to prototype development, this task will support the development of detailed plans for ground demonstrations for proof-of-concepts. The specific facilities, test plans, and test procedures for these ground demonstrations will be defined. Requirements and schedules for these test facilities will be defined and coordinated with the facility operators.

The opportunity for flight demonstrations for proof of concept will be assessed under this task.

Trajectory Control Analyses

For the Pathfinder Program, trajectory control requirements will differ from current earth-orbit, manned vehicle operations in that many of the constraints such as lighting, ground tracking coverage, and periodic space-to-ground communications are not applicable. Instead, trajectories must be designed to maximize the reliability of rendezvous and docking in lunar and planetary orbits.

This task defines, from an operational viewpoint, the functional requirements for automated rendezvous, proximity operations, and docking. Trade studies are performed to assess options and benefits associated with the operations of a mixed fleet of manned and unmanned vehicles. Detailed trajectory control performance requirements will be defined and a plan for ground/onboard software partitioning will be recommended.

Guidance, Navigation and Control System Integration

This task will evaluate proposed AR&D supporting technologies for compliance with the integrated system functional requirements developed under this work package. This evaluation will rely heavily on high fidelity simulations of aspects of operations of vehicles in earth, lunar, and planetary orbits and trajectories. Six degrees-of-freedom (6 DOF) simulations will support performance analyses for a particular vehicle's GN&C system. As an example, such simulations would be used to compare performance for various guidance options.

A 12 DOF methodology will be used to integrate multivehicle interactions including relative motion, orbital mechanics effects, plume impingement, contingency operations, etc. Such simulations will be used to validate the performances of integrated GN&C systems against the mission and system requirements. They will also support trade studies for performance budget allocations among the

2.4.5 Milestones/Deliverables

The milestones and deliverables for this work package are summarized in table 2.3. Workshops/technical interchanges will be conducted at the end of the third quarter of each fiscal year. The focus of the FY '89 workshop will be the status of development of GN&C algorithm options and trade studies of candidate sensors. The FY '90 workshop will focus on technology status of artificial intelligence for AR&D and technologies for sensors and mechanisms for a near-term AR&D demonstration. The FY '91 workshop will report on progress of the near-term technologies, initial plans for ground and flight demonstrations, and the identification and progress of technologies for a far-term AR&D demonstration. The FY '92 workshop will report on results of ground proof of concept demonstrations of the near-term capabilities and progress of development of the far-term AR&D technologies. The FY '93 workshop will focus on the plans and results of the near-term flight demonstration and the status of the far-term AR&D technologies.

WORK PACKAGE MILESTONES/DELIVERABLES	FY 89	FY 90	FY 91	FY 92	FY 93
AR&D PRELIMINARY RQMTS REVIEW (PRR) - SYSTEM REQUIREMENTS CORRELATED TO MISSION REQUIREMENTS AND DRMs - TRAJECTORY CONTROL REQUIREMENTS - INTEGRATED GN&C REQUIREMENTS		▲ Near-Term		▲ Far-Term	
AR&D SYSTEM DESIGN REVIEW - FINAL SYSTEM REQUIREMENTS - FINAL TRAJECTORY CONTROL RQMTS - FINAL INTEGRATED GN&C RQMTS		▲ Near-Term			▲ Far-Term
AR&D PRELIMINARY DESIGN REVIEW - GN&C OPTIONS EVALUATIONS - VALIDATED SYSTEM RQMTS - PERFORMANCE ENVELOPE DEFINITION			▲ Near-Term		▲ Far-Term
AR&D GROUND DEMONSTRATIONS - PLANS - RESULTS ANALYSES			▲ Near-Term ▲ Near-Term		▲ Far-Term ▲ Far-Term
AR&D FLIGHT DEMONSTRATIONS - PLANS				▲ Near-Term	

Table 2.3 - Pathfinder AR&D Systems Integration milestones and deliverables.

2.4.6 Resource Allocation

Table 2.4 presents the estimated resource allocations for the tasks under this work package.

Development and refinement of general purpose rendezvous guidance schemes (i.e Battin-Vaughan-Lambert formulation).

During the initial Pathfinder Program effort, AR&D GN&C development will be directed towards the requirements of the Mars Rover Sample Return mission (MRSR). GN&C analysis, development, and evaluation will be phased such that early demonstrations of desired capabilities can be supported. These demonstrations will initially be ground based experiments, eventually migrating to more ambitious flight demonstrations. By their nature, the GN&C algorithms, techniques, and formulations produced under the GN&C work package element can be tested and evaluated using digital simulations. Nonetheless, when the opportunity arises, testing in the actual environment with flight type hardware interfaces will be pursued.

2.5.2 Technical Approach

The basic approach to GN&C technology development is to proceed from a point design for a GN&C system to one that is optimized for and integrated with a candidate mission and vehicle(s). The first step in this process is to identify integrated GN&C functional requirements for a candidate mission (i.e. MRSR). Proposed AR&D GN&C technologies will then be evaluated in terms of compliance with these requirements.

Major technology challenges for AR&D are the development of GN&C algorithms which provide highly reliable rendezvous and approach operations without manual control or crew participation. Current GN&C capabilities, while relatively mature, require a high degree of crew participation and are designed to meet constraints associated with crew and ground interactions. Furthermore, GN&C capabilities for automated docking have not been developed.

Several GN&C options have been identified for autonomous rendezvous, approach,and docking operations. Techniques for rendezvous and approach guidance will be evaluated. Similarly, GN&C options for proximity operations and docking will be evaluated. For these operations,coordinated, simultaneous rotational and translational control will be key to efficient and well performing docking operations. The options will be assessed and evaluated against design reference mission (DRMs) for the Pathfinder Program. Major evaluation criteria include accommodation of candidate sensor options, maximum opportunities (nominal and contingency)to complete rendezvous and docking, and reliability of these operations.

Another major GN&C design challenge is multivehicle control. The design must consider joint control operations of the chaser and target vehicles just prior to docking, damping of docking transients and control handover following docking, and stabilization of the docked configuration.

2.5.3 Description

The primary focus of the GN&C development work package task is to identify the requirements for a self contained autonomous rendezvous and docking algorithm. Two classes of docking targets have been identified: cooperative (characterized as having some type of docking aid such as a transponder, beacon, or reflector array), and noncooperative (not equipped with any docking aid). Additionally, rendezvous targets that are both active and passive in terms of maneuvering, attitude control, and powered/unpowered tracking aids will be addressed. The special GN&C requirements posed by uncontrolled or tumbling targets will be assessed. Specific GN&C requirements imposed by each target class will be delineated,with an objective for the GN&C designs to accommodate both the near-term sensors and advanced sensors.

The GN&C requirements on relative bearing, range, range rate, and attitude data will be assessed against the performance of candidate sensors. In this fashion, performance requirements and capabilities will be traded between the GN&C suite, sensors, and effectors and docking mechanisms. An example of the interaction of requirements between GN&C and effectors/mechanisms is in the robustness of the docking system. A sophisticated, highly accurate GN&C system would permit the use of a simple and very limited (with respect to range of operation, impact attenuation capacity, etc.) docking mechanism. Similarly, a highly capable docking mechanism could tolerate uncertainties in the terminal conditions of the docking sequence that a less refined GN&C complement might introduce. This trade of responsibilities and functional capabilities among the various work package elements will result in an integrated mission system as opposed to a loose collection of point designs.

The requirements on trajectory design and trajectory control will be evaluated for the MRSR mission. For AR&D operations, the traditional mission design constraints such as lighting and communications and tracking coverage that characterize manned operations, will be supplanted by requirements for reliability and robustness of the automated sequence in earth, lunar, or Mars orbits.

Artificial intelligence (AI) and expert system technologies will be evaluated for applicability to GN&C systems for AR&D. Use of AI is expected to yield a system that is capable of a rich variety of responses to external stimuli as opposed to a more limited "canned" set of routines and procedures. It is expected that the MRSR mission operations conducted in Mars orbit will rely to some extent on AI due to the requirement for robust autonomous operations because of the prohibitive light travel time from earth.

2.5.5 Milestones/Deliverables

The milestones and deliverables for the GN&C work package are summarized in figure 2.4.

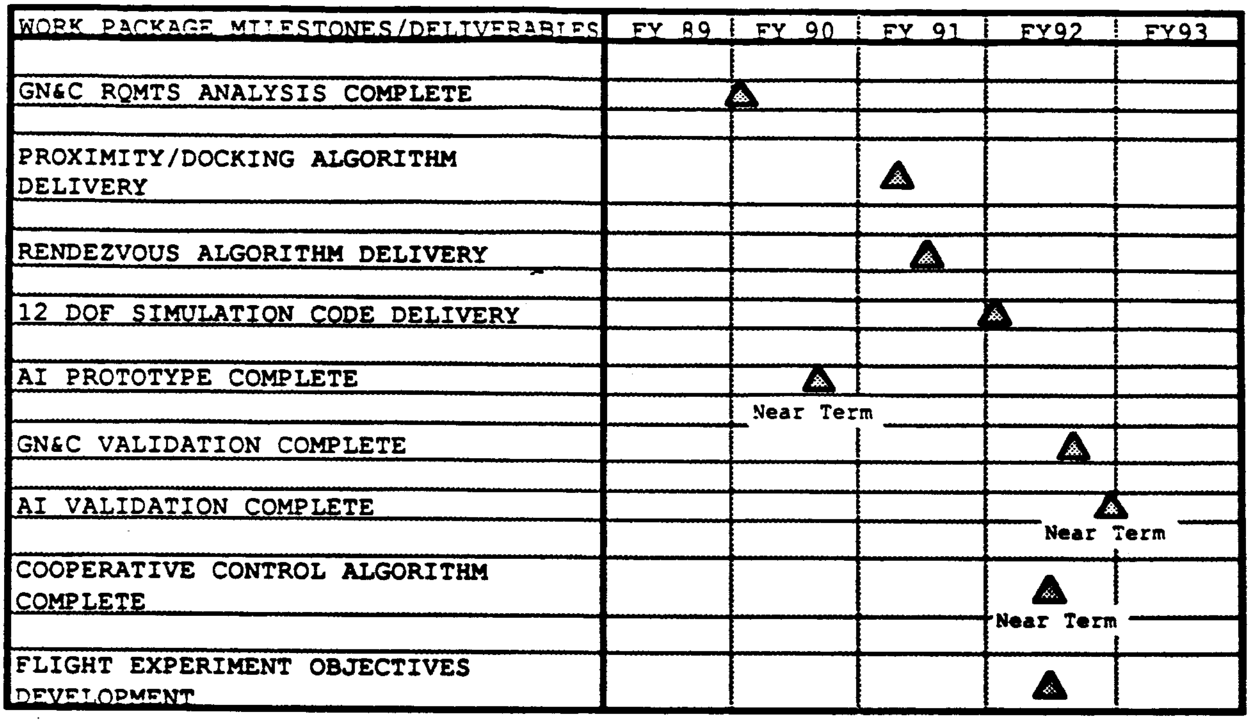


Figure 2.4 - AR&D GN&C Milestones and Deliverables.

2.5.6 Resource Allocation

Table 2.5 presents the estimated resource allocations for the tasks under this work package.

GN&C WORK PACKAGE RESOURCE ALLOCATION ($K)

FY 89	FY 90	FY 91	FY 92	FY 93
400	1150	1750	2000	1800

Table 2.5 - AR&D Estimated resources for GN&C development.

able, studies will be undertaken to determine the range threshold at which the handover from one sensor to another should occur.

It must be recognized that from a strictly technical standpoint, there is no single "best" approach to the sensor requirements for a particular mission. Recognizing this, and the importance of cost and schedule impacts, the selected approach is to identify and characterize candidate tracking techniques and hardware implementations including any advanced DDT&E and flight hardware development that has been previously accomplished. An assessment will be made of the capabilities and limitations (including operating regimes and ability to track passive, non-cooperative targets in darkness) and of the advantages and disadvantages of each technique.

Another early goal of this work package is to perform and analyze the results of a trade study to identify those sensor technology development areas that are cost effective, improve performance and will reduce development and schedule risks. These technologies include optical and radio frequency tracking and active versus passive detection. The technologies for laser and radio frequency tracking sensors are sufficiently mature that they are candidates for a near-term demonstration of AR&D. These technologies require performance extensions and enhancements to meet the unique Pathfinder requirements. In contrast,advanced systems such as vision sensors will require longer term technology development. They offer the potential for performance equal to that of the laser and radio frequency sensors, possibly with little if any requirements on the target vehicle (e.g., transponders and corner reflectors). They also can support the identification and discrimination among several targets.

As candidate sensor approaches proceed from concept, through simulation, breadboard, and finally to prototype phases, the result of each development phase will be subject to test and evaluation either through digital simulation or in a test bed facility. The sensor prototypes will be tested in thermal/vacuum facilities and incorporated in demonstrations using flat-floor facilities. The product of each phase will be made available to other AR&D work packages such that integrated system level tests can be performed.

A leading candidate sensor for intermediate and short range attitude and ranging data determination is the JSC developed Laser Docking Sensor. This sensor is manifested on STS-TBD for a flight demonstration. A high priority will be placed on enhancing the effective range of operation of this existing sensor. Sensor development can be divided into two phases, a near term and a far term. The near term effort will concentrate on improving the performance and operating regimes of existing devices and technologies. For the long term, emphasis will be placed on identification and advanced development of new sensor technologies, particularly where such technologies offer a significant increase in capability. As might be expected, some technical approaches span both the near namic load tests. In all cases, the models and prototypes will be made available to other program elements for integrated tests and total system verification. A balance is essential between the characteristics and capabilities of the mechanisms, sensors, and GN&C system of the MRSR. An aggressive policy of disseminating requirements and performance data among all Pathfinder work packages will support maintaining this balance.

2.6.3 Schedule

Figure 2,5 depicts the development schedule for AR&D sensors and mechanisms. Note that for the area of sensor development, a far-term effort succeeds the initial development phase. This far-term activity is likely to concentrate on technologies that permit acquiring and tracking passive or otherwise noncooperative targets at long ranges.

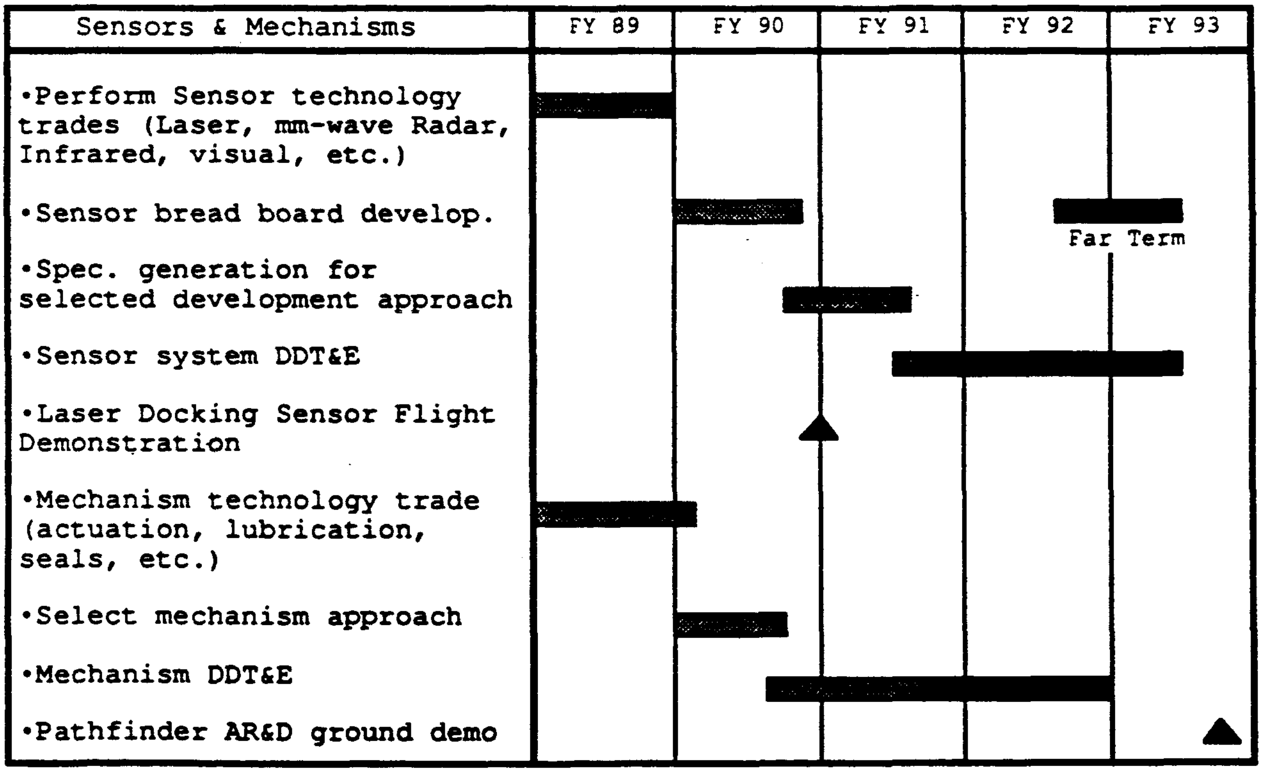


Figure 2.5 - AR&D Sensor and Mechanisms development schedule.

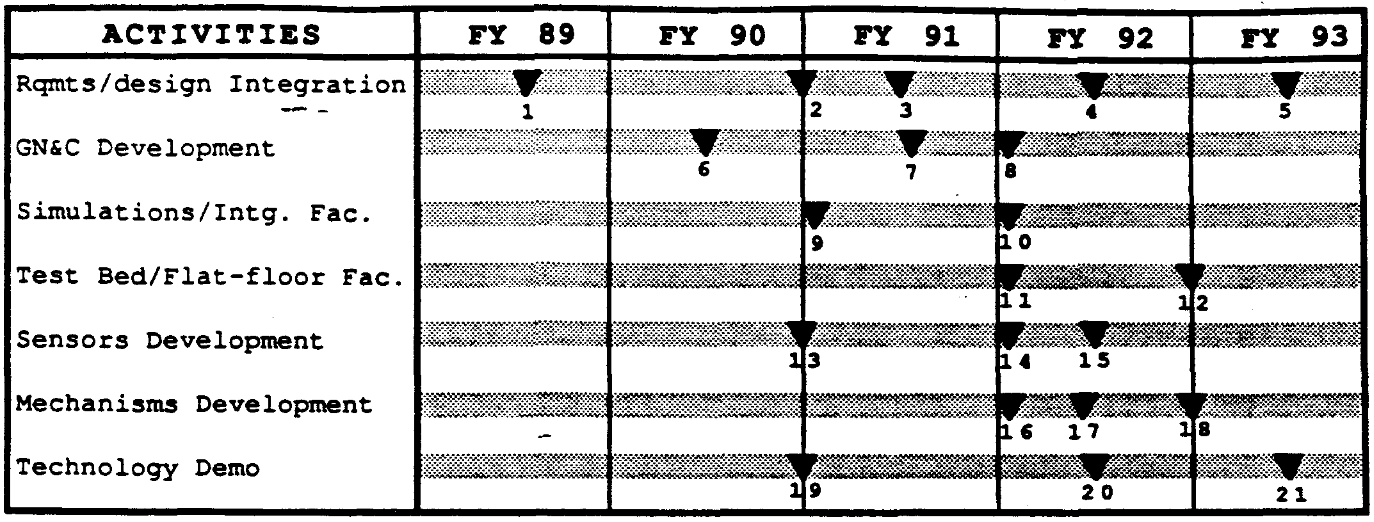
2.7 Five Year Planning Summary

2.7.1 Fiscal Year 1989 Schedule

The focus of the FY '89 AR&D activities will be to:

- establish AR&D technology requirements, which are correlated to the Pathfinder mission requirements
- define preliminary requirements for trajectory control and GN&C systems
- initiate development of GN&C algorithm options
- assess the requirements and benefits of artificial intelligence to support AR&D
- perform sensor trade studies
- initiate basic research in mechanism technologies, correlated to the unique requirements for Pathfinder missions.

The schedule for FY '89 is provided in figure 2.7.



DELIVERABLES

1 - TECHNOLOGY REQUIREMENTS DEFINED
2 - NEAR-TERM MISSION REQUIREMENTS/SCENARIO DEFINED
3 - NEAR-TERM GROUND DEMONSTRATION TEST PLAN PUBLISHED
4 - NEAR-TERM FLIGHT DEMONSTRATION TEST PLAN PUBLISHED
5 - FAR-TERM MISSION REQUIREMENTS/SCENARIO DEFINED
6 - NEAR-TERM GN&C POINT DESIGNS VERIFIED
7 - NEAR-TERM INTEGRATED GN&C PROGRAMS VERIFIED
8 - NEAR-TERM GN&C PROGRAMS INSTALLED IN FLAT-FLOOR FACILITY
9 - 12 DOF SIMULATION OF NEAR-TERM AR&D CAPABILITIES CERTIFIED
10 - NEAR-TERM AR&D CAPABILITIES DEMONSTRATED IN 12 DOF SIMULATION
11 - FLAT-FLOOR FACILITY(S) CERTIFIED FOR NEAR-TERM AR&D DOCKING DEMONSTRATIONS
12 - FLAT-FLOOR DEMONSTRATION OF NEAR-TERM AR&D CAPABILITIES COMPLETED
13 - NEAR-TERM SENSOR(S) BRASSBOARD/BREADBOARD COMPLETED
14 - NEAR-TERM SENSOR TEST ARTICLE INSTALLED IN FLAT-FLOOR FACILITY
15 - THERMAL/VACUUM QUALIFICATION OF NEAR-TERM SENSOR(S)
16 - MECHANISMS ENGINEERING PROTOTYPE DELIVERED TO MATING TEST FACILITY
17 - THERMAL/VACUUM QUALIFICATION OF PROTOTYPE MECHANISM COMPLETED
18 - ACCELERATED LIFE TESTING OF PROTOTYPE MECHANISM COMPLETED
19 - CODE M LASER DOCKING SENSOR FLIGHT DEMONSTRATION RESULTS ASSESSED
20 - NEAR-TERM AR&D GROUND DEMONSTRATION COMPLETED
21 - NEAR-TERM AR&D FLIGHT DEMONSTRATION

Table 2.7 - **Five-Year Schedule, Milestones and Deliverables.**

2.7.3 Milestones, Accomplishments, & Deliverables

The milestones, planned accomplishments, and deliverables for the Five-Year plan are defined in table 2.7.

Each arena has different uses for the automated rendezvous and docking capability. It may not be possible to combine all the requirements into one package capable of satisfying all users. Therefore, the Pathfinder project will develop a set of core technology that can then be used by any of the arenas to further develop their desired capability. This level of cooperation may be all that is required to satisfy the arenas. However, if a core set of requirements can be developed that are larger in scope, there may be sufficient synergism and economy of scale to make it worthwhile for the arenas to assist in funding the technology development efforts of the Pathfinder AR&D.

Our goal is to identify a core set of requirements that is common to all arenas and will satisfy 80% of their total capability requirements. If an arena wanted to have the capability, they would then be expected to assume responsibility for completion of the technology development effort using their own resources. At the same time each arena will be encouraged to contribute some resources to the Pathfinder AR&D project to bring the project further along to fruition than if Pathfinder AR&D funding were the sole source. This synergism will allow the project to reach technology demonstration level 5 on schedule, permitting the arenas to then pick up at level 5 and continue their own specialized development activities.

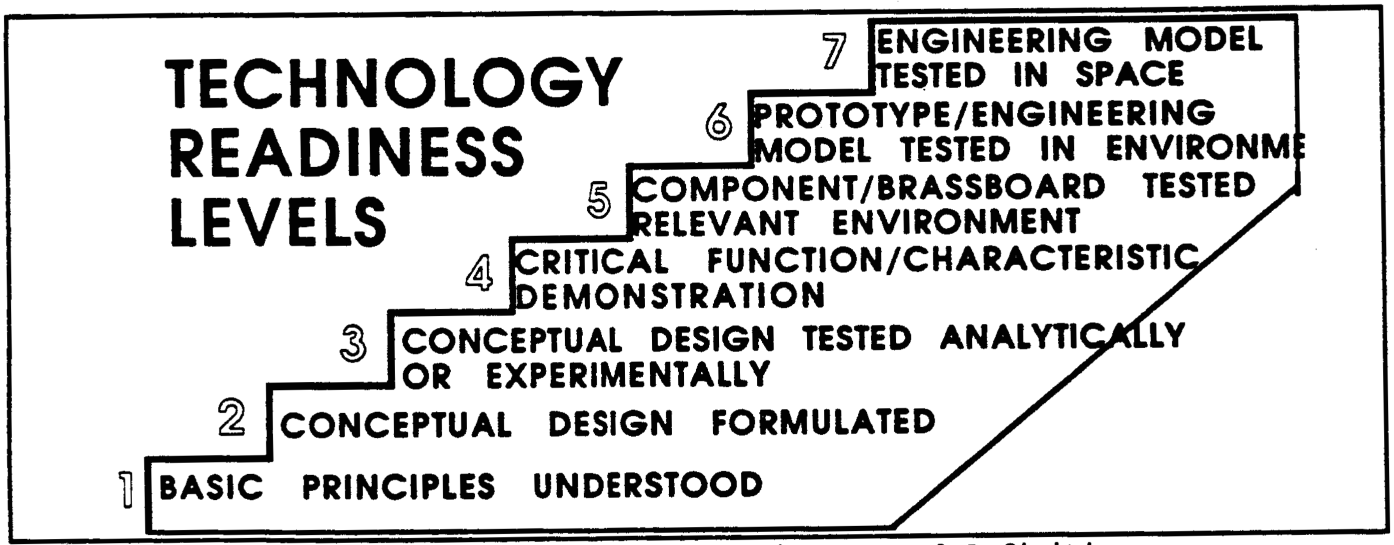


Figure 2.8 - OAST Technology Readiness Level Definitions.

2.8.2 Arenas

Mars Rover Sample Return (MRSR) Mission (Code E and Z)

The requirements for this arena are autonomous operation, high reliability, with low weight and volume. Because the spacecraft will be traveling to and operating at Mars for a lengthy period of time before conducting rendezvous and docking, the system must be highly autonomous and reliable.

SECTION 3

Contracting Plans

3.1 Overview

Implementation of the Pathfinder AR&D Project will include AR&D Systems Engineering and Integration, GN&C and sensor and mechanism products from JSC. MSFC will contribute to the development, testing and demonstration of docking and JPL will contribute to the development of advanced guidance and navigation strategies.

3.2 Industry

Development of AR&D prototype components will be contracted to industry. Early engineering models will be evaluated in NASA laboratory facilities and used to develop concepts for long range AR&D planning.

3.3 Universities

Opportunities to involve universities or non-profit organizations in AR&D technology development will be sought. Possibilities include participation in trade studies of alternative sensor technologies, assessment of AR&D artificial intelligence applications, simulation enhancements and participation in workshops to select competing AR&D approaches.

SECTION 4

FACILITIES PLANS

4.1 Overview

Facilities used in support of Pathfinder Autonomous Rendezvous and Docking (AR&D) fall into two classifications:

1. Laboratories and Computing
2. Demonstration and Testing facilities.

As a general goal, the Pathfinder AR&D development project will not require the construction of any new facilities, either for development or for testing. Rather, maximum use will be made of existing and planned facilities, computational resources, etc.

While it is possible that there might be a limited requirement for additional computing capacity, the need will not be on such a scale as to justify investment in a dedicated "brick and mortar" facility. Contractors involved in AR&D support will be expected to supply the requisite floor space and computer hardware resources. This is not expected to present any problem in that the total requirements for AR&D are small, and AR&D code can be hosted in existing government and contractor owned machines. Computer facilities will support the design, development, and test and simulation activities for AR&D. Physical facilities will house test fixtures and related evaluation support equipment.

AR&D test beds and related facilities will be essentially modifications or enhancements to existing facilities. The most significant resource required by AR&D are the flat-floor facilities that will support evaluations and demonstrations. These are existing facilities that will be used on a time sharing basis with other test sponsors.

4.2 Laboratories and Computing

A very mature base of 6 DOF and 12 DOF simulations capable of supporting the Pathfinder AR&D project is available within NASA. These simulations have been used to develop and test the performance of rendezvous and docking for the Apollo, Shuttle, OMV and Space Station programs.

Enhancements to existing software must be defined to support Pathfinder AR&D WBS elements such as automatic proximity operations, artificial intelligence aspects, general purpose guidance algorithms, sensor models, planetary vehicle models, and planetary environment models.

The following are brief descriptions and specifications for several demonstration and testing facilities that the Pathfinder AR&D project might seek access to:

JSC Precision Air Bearing Facility (PABF)

This facility has been in service since 1976. It provides the capability for reduced friction simulations of zero gravity in support of development of hardware and operational procedures for NASA spaceflight programs.

The air bearing table is 24 feet in length by 21 feet wide. The twenty-one 6 inch thick steel plates that comprise the table are precision ground to a tolerance of ±0.0005 inches over any arbitrary 2 foot by 2 foot section. The entire table can be leveled to within 0.011 inch. This degree of precision permits a unit under test to "fly" at a reduced height above the table surface and under reduced pressure, thus minimizing the skating effect commonly encountered in similar facilities. The steel construction of the bearing surface endows it with great durability. The surface, as cast, has a Brinnell hardness of 180° to 220°, offering a high resistance to scratching and gouging.

Figure 4.1 - Precision Air Bearing Facility (PABF) flat-floor.

The PABF has been employed in Manned Maneuvering Unit (MMU) testing, evaluation, and flight training. Its sensitivity allows the evaluation of dynamic responses to disturbances induced by factors such as crew limb motion and umbilical/tether dynamics.

Dynamic Overhead Target Simulator (DOTS)

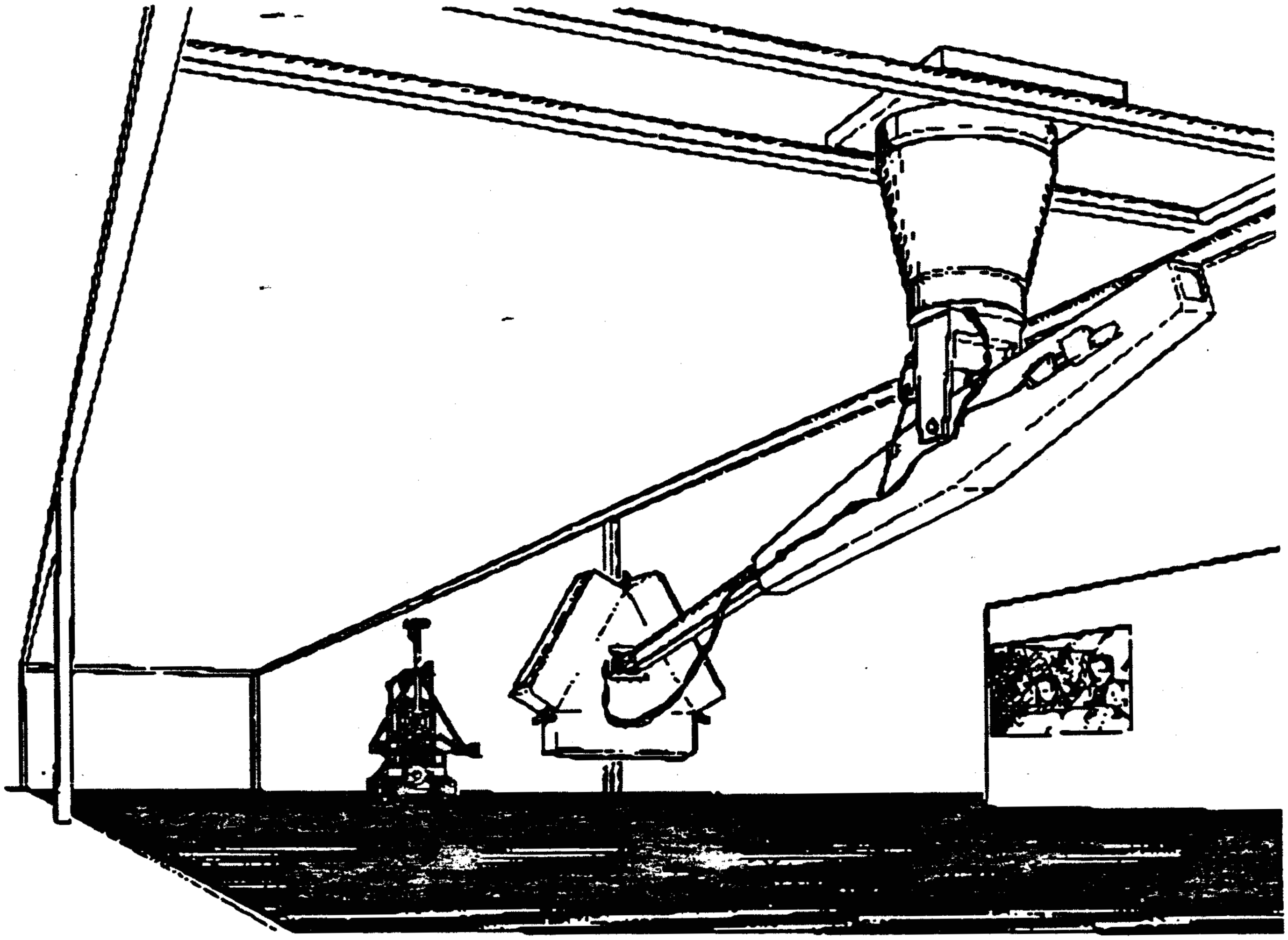


Figure 4.2 - Dynamic Overhead Target Simulator

Artist's concept of the dynamic target simulator suspended above the flat floor is shown here. This six-degree-of-freedom simulators being mounted on a computerized overhead crane which allows precision translation of full-scale powered mockups or test articles throughout the entire volume above the flat floor. using the DOTS and the mobility unit rendezvous and docking with an unstable satellite can be simulated.

JSC Space Environment Simulation Chambers A and B

In aggregate, these two facilities represent a NASA capital investment of approximately $73 million. Chamber A is a stainless steel vessel 19.8 meters in diameter and 36.6 meters high. Its working volume enclosed within a 90° Kelvin heat sink shroud is approximately 17 by 27 meters. Test specimen access is through a 12.2 meter diameter door.

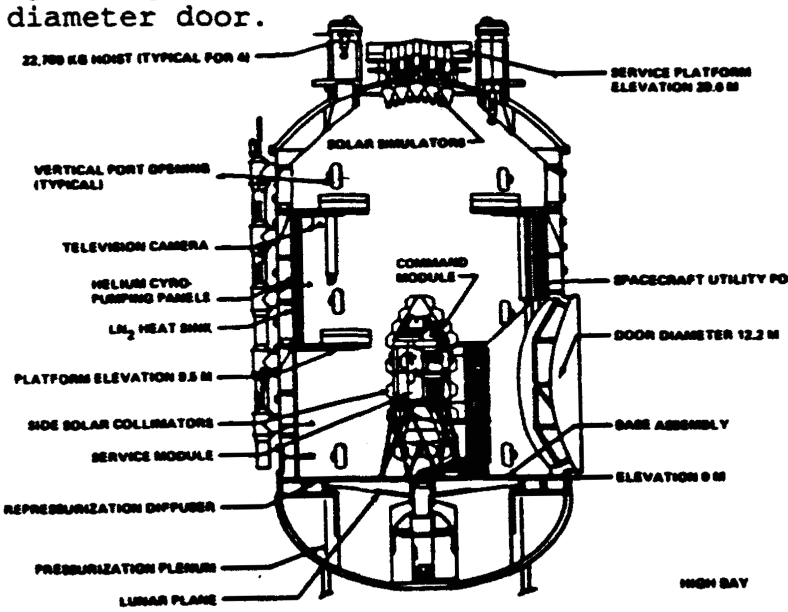


Figure 4.4 - Thermal/Vacuum chamber 'A' general arrangement.

A modular system of carbon-arc solar simulators provides a solar field that is 4 meters in diameter and 10 meters high. The intensity of the solar field is selectable from 0.5 to 1.0 solar constant, with a uniformity of ±20 percent. The chamber floor can accommodate a load of 90,800 kg and may be rotated during tests to provide directional cycling with respect to the side mounted solar simulators. Time to pump down to thermal-vacuum test conditions is 7 hours.

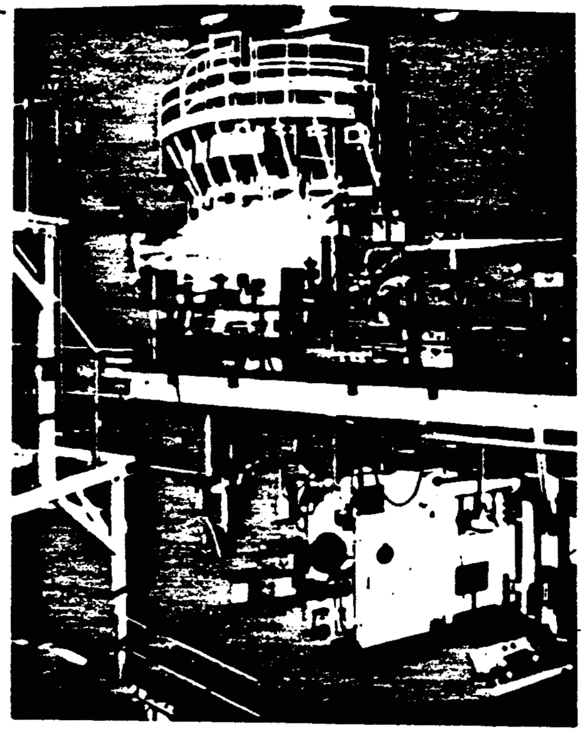


Figure 4.6 - Thermal/Vacuum chamber 'B' and ancillary equipment.

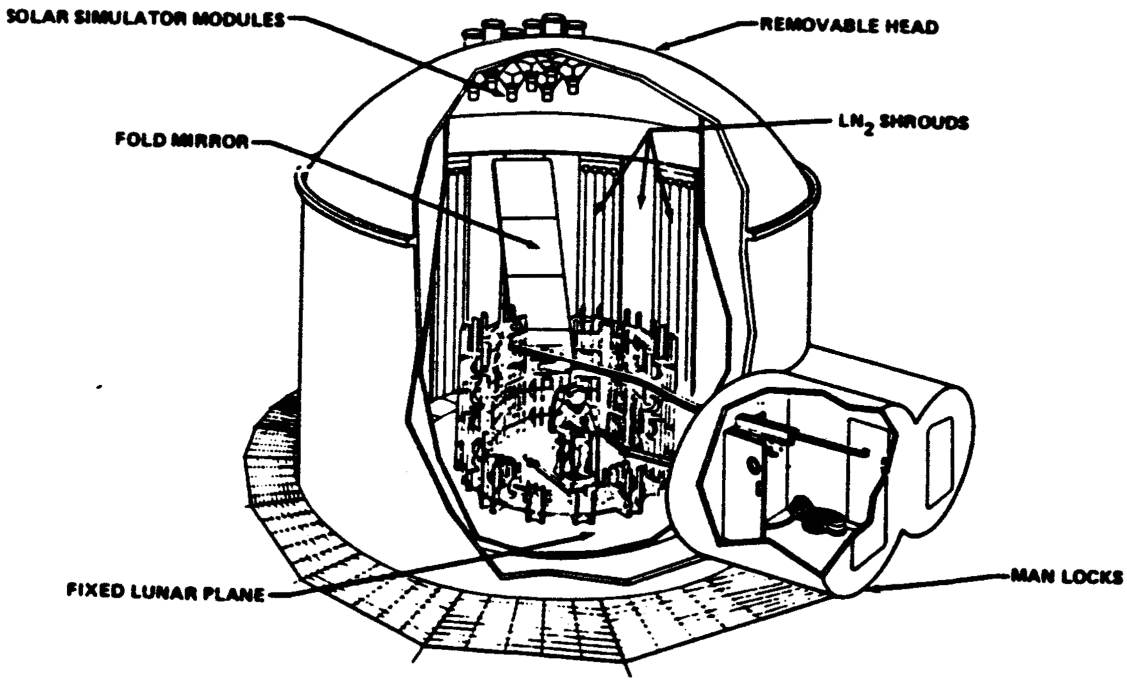


Figure 4.7 - Chamber B general arrangement.

Ultrahigh Vacuum Space Simulation Chamber D

This facility offers the capability to provide a thermal vacuum environment for testing small spacecraft or subsystems that conform to an envelope not exceeding 1.8 by 4.3 meters. Test articles weighing up to 906 kg can be accommodated. Through the use of a variety of pumping systems, including a mechanical pump, a cryopumping system, LN_2 oil-diffusion pump, a getter-ion system, and a titanium sublimation pumping system, chamber vacuums on the order of 10^{-9} torr are obtainable. Normal pumpdown times are 2 hours to $\approx 10^{-5}$ torr and 24 hours to ultimate pressure.

The chamber shell can be electrically heated to a temperature of up to 600° K, and a xenon short arc solar simulator is available. Intensity of the solar simulator is selectable between 0.46 to 1.0 solar constant to a tolerance of ±8 percent. Custom albedo and planetary radiation simulators are available, as are fixtures to rotate and tilt test articles relative to the solar and thermal flux fields.

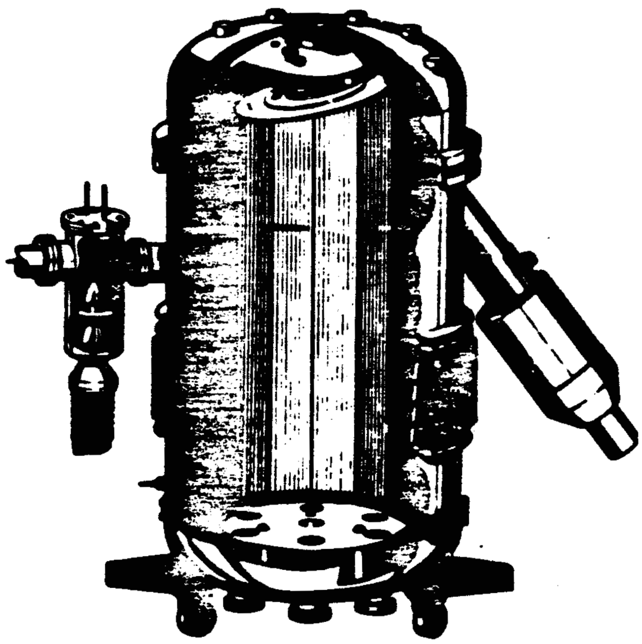


Figure 4.8 - Ultrahigh vacuum facility cutaway view.

Figure 4.9 - Inertial Components Laboratory.

Electromagnetic Compatibility Test Laboratory

The Electromagnetic Compatibility (EMC) Test Laboratory at JSC supports EMC evaluation and certification for flight and ground support equipment. This facility consists of two shielded enclosures that provide radio frequency (RF) isolation from the facility ambient environment. Typical shielding effectiveness for the 280 square foot enclosed area is 100 dB.

Main equipment items include an automatic spectrum plotting system consisting of a network of receivers sensitive to a frequency range of 30 Hz to 10 GHz, and a Hewlett-Packard HP-8568 automatic spectrum analyzer system. Also available is a set of signal generators and a comprehensive line of general purpose ancillary test equipment.

Electro-optical and Laser Laboratory

This facility at JSC allows complete analysis of the behavior of active and passive optical and laser systems. The heart of the laboratory is a cylindrical vacuum tube 80 meters long and 4 meters in diameter. This tube, housed in a temperature controlled (±2° F) tunnel, can be evacuated to 10^{-3} torr, and its interior finish is optimized for the suppression of unwanted reflections. If desired, gases other than air can be introduced into the tube. Test carts, the locations of which are adjustable, are provided inside the tube.

platforms, a position reference system, two-DOF and six-DOF target positioners, a computer-based theodolite system, and a fiber optic network.

OPTICAL COMMUNICATIONS DDT&E AREA supports design, development, test, and evaluation of optical communication systems. Capability exists in the areas of fiber-optic communication, short-range flooded volume communication, and long-range point-to-point communication.

Radar Boresight Range Facility

The free-space range at JSC was expressly designed for development and testing of spacecraft rendezvous radar systems. The facility is housed in a structure enclosing approximately 1,250 square feet of floor space and uses an antenna range transmitting tower located 2,500 feet away.

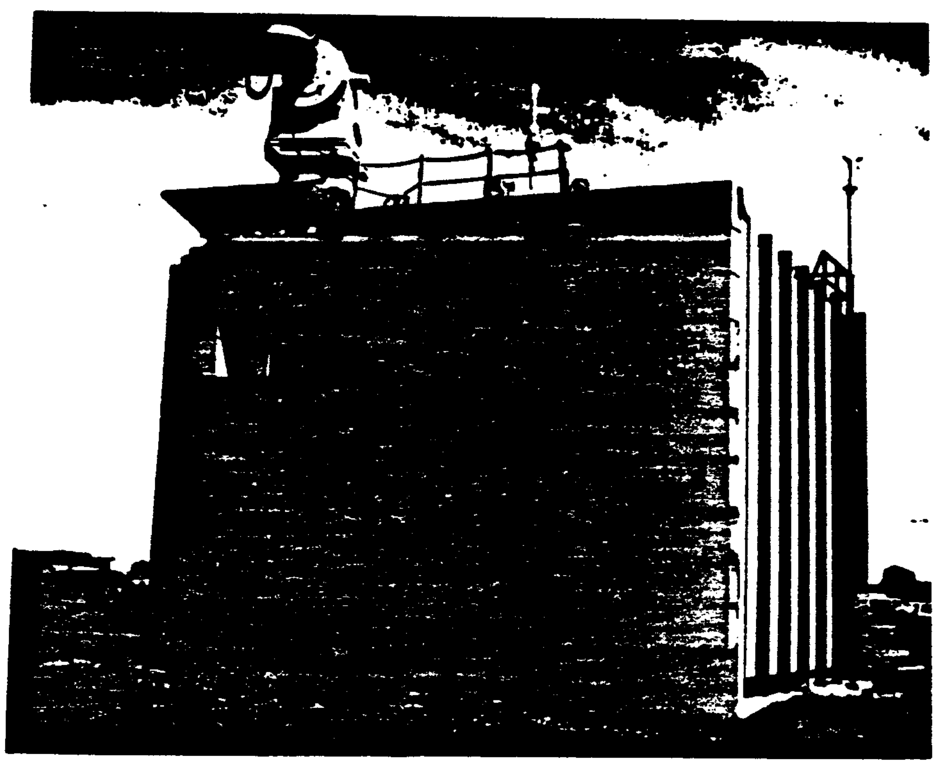


Figure 4.11 - Radar boresight facility antenna positioner.

To meet the stringent requirements on antenna positioning, a heavy-duty three axis antenna positioner mounted on temperature-stabilized columns is employed. The capability exists to observe and record field strength variation across the receiving aperture, the degree of polarization of the transmitted signal, and the absolute gain of the antennas under test. Control and recording in-

SECTION 5

In-Space Research and Technology

Technology for rendezvous and docking of piloted space vehicles is very mature and includes historical performance data from actual in-space missions. Translation of piloting techniques to accomplish these critical tasks in an autonomous manner, however, is not straight forward. Flight crews who performed these missions had extensive training preparation in complex man-in-the-loop real-time simulators with realistic visual presentations. Extravehicular-activity provided a rich capability to address anomalies and achieve mission success. Application and verification of expert systems technologies to implement autonomous AR&D operations will require careful planning and performance evaluation.

Pathfinder technologies must build upon the rich heritage of piloted rendezvous and docking experience while providing on-board intelligence and instrumentation to assess anomalies and select alternate means to achieve mission objectives. Requirements for redundancy needed to achieve long-term planetary mission objectives which include long periods of dormancy of electronic and mechanical systems must be developed and, to the extent possible, demonstrated in an in-space environment that includes realistic lighting and thermal effects.

As NASA transitions to a mixed fleet capability, there will be opportunities to define in-space research and technology flight demonstrations using the NSTS, OMV, Space Station and expendable vehicles to build sufficient confidence to commit the very costly vehicles and systems that will be required for planetary exploration to a mission.

The management structure adopted for Pathfinder projects will be a key factor in capitalizing on high leverage opportunities for synergism between diverse NASA programs.

SECTION 6

Technology Transfer Planning

TBS

APPENDIX A

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11. "Leadership and America's Future in Space", Report to the Administrator, by Dr. Sally K. Ride, November 1987.

APPENDIX B

PROGRAM ROLES, RESPONSIBILITIES, AND ACCOUNTABILITY

A Lead Center management organization structure has been proposed to manage the Pathfinder Automated Rendezvous and Docking (AR&D) Project. This type of management structure is well suited for defining and controlling these types of research and technology projects. Code RC has been designated the overall Program Manager for the Pathfinder AR&D effort, with an intercenter working group responsible for defining and planning the initial effort and serving as a steering committee. JSC has been designated as the Lead Center for managing the effort and providing the technical coordination with NASA HQ and the other participating centers.

Figure B.1 shows the management structure that has been selected.

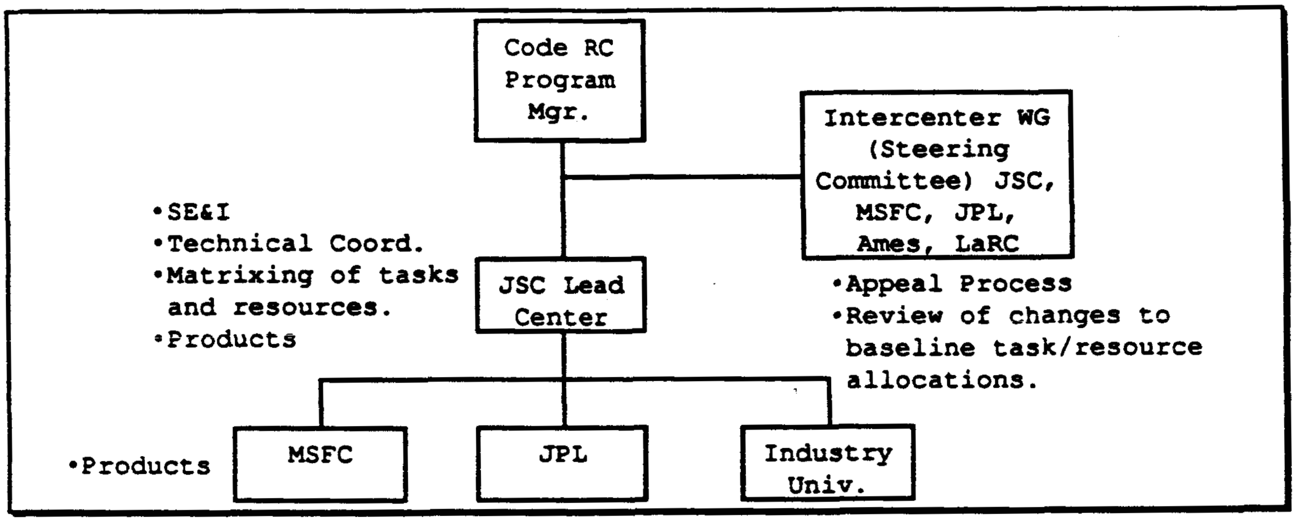

Figure B.1 - Management Structure for Pathfinder AR&D Project.

B-1 PROGRAM ROLES

NASA HQ (Code RC)

Code RC is the liaison between the Lead Center and the fiscal agents within NASA Headquarters to coordinate the budget requirements of the AR&D Project. They provide overall management guidance and ensure that the objectives of the AR&D project are compatible with the overall needs of Code RC and NASA. They also function as liaison between the Lead Center and other codes at NASA HQ.

B-2 PROGRAM RESPONSIBILITIES

NASA/HQ (Code RC)

Code RC is responsible for the overall management of the AR&D Program. They are responsible for guiding budget requests through the necessary coordination process, and for transferring the resultant resource allocation to each center for subsequent allocation to the different tasks. The AR&D Program Manager will chair Steering Committee meetings and act upon their advisory recommendations as appropriate.

Johnson Space Center (JSC)

JSC, as the Lead Center, is responsible for the project management of the technology efforts of JSC and the other participating centers. They will provide the technical coordination between the participating centers' technology efforts and recommend resource and task allocations to Code RC. JSC is responsible for making all reports to NASA HQ on the progress of the technology efforts, and will track schedules and progress against agreed upon milestones. They will manage the scheduling of deliverables and tasks so as to ensure quality products in a timely manner. JSC shall have a representative on the Intercenter Working Group Steering Committee.

Marshall Space Flight Center (MSFC)

MSFC is responsible for managing the research tasks assigned to them within the budget and time constraints spelled out in the AR&D Project Plan. They will provide the deliverables called for in the AR&D Project Plan. MSFC shall have a representative on the Intercenter Working Group Steering Committee.

Jet Propulsion Laboratory (JPL)

JPL is responsible for managing the research tasks assigned to them within the budget and time constraints spelled out in the AR&D Project Plan. They will provide the deliverables called for in the AR&D Project Plan. JPL shall have a representative on the Intercenter Working Group Steering Committee.

Ames Research Center (ARC)

As an interested center, ARC may propose related technology efforts for funding within the AR&D Program in later years. For efforts that are funded, ARC will become a participating center and will be responsible for managing the research tasks they are assigned within the budget and time constraints of the Project Plan. ARC shall have a representative on the Intercenter Working Group Steering Committee.

Project Plan. Deliverables and required reports will be submitted to JSC for coordination with Code RC.

In cases of disagreement between the Lead Center and one or more participating center, the issue may be reported to the Intercenter Working Group Steering Committee. The Intercenter Working Group Steering Committee will listen to the issues involved and make a recommendation to the AR&D Program Manager.

LIST OF FIGURES

ACKNOWLEDGEMENT

This document has been compiled through the efforts of many individuals at JSC and other NASA centers. Special acknowledgement is in order for Roscoe Lee, TRW-Houston, Wayne McCandless, Lockheed ESC-Houston, members of the JSC AR&D Working Group and members of the intercenter AR&D Working Group for their contributions to this document.